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PROFIT PLANNING UTILIZING LINEAR PROGRAMMING IN AN INTEGRATED OIL COMPANY

by

NIALL HENRY SADLER

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled PROFIT PLANNING UTILIZING LINEAR PROGRAMMING IN AN INTEGRATED OIL COMPANY submitted by Niall Henry Sadler in partial fulfilment of the requirements for the degree of Master of Business Administration.

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Date.....May 14, 1971.....

ABSTRACT

There is much in the literature to suggest that excessive suboptimization of profits may occur by emphasizing the allocation of activities in functions of a system. The purpose of this study was to determine if planning on a functional basis in a vertically integrated oil company results in suboptimization of profitability. In order to investigate this, a linear programming model of a hypothetical oil company was constructed.

Emphasizing the allocation of activities in functions was found to result in suboptimization of profitability. The difference in total profitability between integrated and functional planning in this study appeared to be in excess of 10 per cent for demand levels where suboptimization of profitability occurred.

ACKNOWLEDGEMENTS

My supervisor, Dr. B.M. Harnden, deserves a special thanks for his assistance and suggestions during the development of this thesis. I would also like to thank Dr. J.W. Rettenmayer, my second reader and Dr. J.C. Sprague, my third reader, for their valuable comments and suggestions.

Acknowledgements must also be given to the oil industry and the Alberta Oil and Gas Conservation Board. Without their assistance it would have been impossible to develop the models used in the study.

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CHAPTER I

INTRODUCTION

The topic of this thesis is profit planning using linear programming at Black Gold. Black Gold is a hypothetical vertically integrated oil company with facilities comprised of a network of sources of crude oil refineries, crude oil and product storage facilities and marketing outlets linked by a transportation system of pipelines and road haulage. The refineries convert the crude oil into a variety of products such as gasoline, diesel fuel, petroleum coke, and asphalt. The proportions and quantities of products made by the refineries depend upon the design of the refinery and nature of the crude oils used in the conversion process.

Black Gold is typical in the industry and employs formal decision models in all phases of its operations. Areas in which the company has found these decision models effective include:

(1) Analysis of data from wells in order to improve crude production and exploration efforts.

(2) Design of refinery units for better performance.

(3) Planning the operations of refineries.

(4) Minimizing the costs of transportation for crude and products.

Linear programming is used for planning refinery operations,

selecting the optimum crude for refineries and analyzing the profitability of processing systems.[1]

Since an integrated decision model is not used excessive suboptimization of profits and costs may occur by optimizing parts of the operations. The purpose of this dissertation is to determine whether optimization of the entire operation will lead to greater profitability than optimizing various parts of the operations. The model formulated is also expected to have use in analyzing existing company facilities and policies and examining the economics of technical innovations.

Historical Background[2]

Many complex technical problems encountered in the petroleum industry may be effectively evaluated by the use of linear optimization models.[3] The initial success of these models in the petroleum industry during the early

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[1] E.D. Kingsbury, "How Imperial Oil Plans with Computers", Canadian Chemical Processing, 46 (September, 1962), pp. 73-74.

[2] The historical background has been abstracted from a summary of relevant papers and books on optimization in the oil industry prepared by B.L. Foster with revisions to provide a more complete historical background. The source of the article is B.L. Foster, "Maximization in the Oil Industry - A Survey", Management Technology, 4 No. 1 (June, 1964), pp. 26-46.

[3] L.K. Cheney, "Linear Program Planning of Refinery Operations", Naval Research Logistics Quarterly, 4 (March, 1957), p. 9.

1950's has lead to the application of linear programming to a wide variety of decision models. Linear programming models have been developed for many areas in the petroleum industry including:[4]

(1) Scheduling production from underground reservoirs.

(2) The economics of crude transportation.

(3) Optimizing refinery operations.

(4) Routing products from refineries to marketing areas.

(5) Product blending.

The pioneers in applying linear programming to the petroleum industry were Charnes, Cooper and Mellon, Symonds and Manne who established the relevance and utility of the method to refinery studies. Blending has been the subject of many reports beginning with a paper by Charnes, Cooper and Mellon on blending aviation gasolines. Articles, mostly on gasoline blending, have also been contributed by Symonds, Manne, Davie, Sheets, Kawaratani et al. and Smith. More general refining optimization studies have been published by Cheney, Dantzig, Marshak, Charnes and Cooper, Vazsonyi, Chenevey, Garvin et al., Lapidus et al. and Mortensen.

Although many of the articles already mentioned discuss some of the difficulties in applying linear programming to refinery problems, an appraisal of them is given by

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[4] Harvey M. Wagner, Principles of Operations Research (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1969), p. 59.

Pfaff. Of these difficulties linear approximation to non-linear functions is the most problematic. The calculation of octane numbers in blending seems to give rise to some of the severest nonlinearities and is described in the work of Healy et al. Another problem in using linear programming is the large number of variables and equations required to formulate a realistic model. Because of the size of some of the models and the limitations in computers, techniques have been developed that decompose linear programs into portions that can be assembled by the computer to yield optimum solutions. The fundamental work on decomposition is presented in an article by Dantzig and Wolfe. Jackson, Wilde, Rosen and Ornea, Singer, Williams, Kirchmayer, Kron and other authors have also published work on decomposition.

Applications of linear programming to crude oil production have been published by Garvin et al., and Lee and Aronofsky. Charnes and Cooper, and Aronofsky and Williams have studied this model and given more computational details in their articles. A field case study has been reported by Attra et al. and a more detailed model has been published by Aronofsky.

There are few publications in the use of linear programming in distribution and marketing in the petroleum industry, however, Lennon gives a simple example of gasoline distribution. More detailed examples are presented by Garvin et al., and Smith, and Robinson provides an application of linear programming for inventory problems. Dantzig

and Ramser give a description of the use of linear programming for the routing of trucks from bulk plants to service stations. Dantzig and Fulkerson have contributed an application for scheduling tankers.

There seem to be no reported examples of the use of linear programming to the optimization of an actual integrated company. However, there are many proposed models including the ones presented by Charnes et al., Smith, Catchpole, Rapoport and Drews, Aronofsky, Markowitz and Newby. A model presented by Ornea and Eldridge gives an example of the use of the decomposition principle for multi-refinery scheduling and crude supply. The hypothetical integrated model developed by Charnes, Cooper and Mellon illustrates the application of linear programming to multi-product and process operations.[5] Rapoport and Drews' approach to linear optimization of an integrated oil company is a mathematical approach to long range investment planning and to operations scheduling for integrated corporations.[6]

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[5] A. Charnes, W.W. Cooper, and B. Mellon, "A Model for Programming and Sensitivity Analysis in an Integrated Oil Company", Econometrica, 22 (1954), p. 193.

[6] Leo A. Rapoport and William P. Drews, "Mathematical Approach to Long Range Planning", Harvard Business Review, 40 (May, 1962), pp. 75-87.

Problem Analysis

The basic technical functions at Black Gold are extracting and refining crude oils and the distribution of products to sales terminals. Therefore, the major processing functions the company is involved in are the extraction, transportation and refining of crude oils and the distribution of products. Within each function coincident activities such as the processing of crude at more than one refinery or the production of crudes from more than one supply area could occur. This occurrence of coincident activities implies that there are a number of alternative methods of performing each function in the company. Therefore, in order to utilize resources effectively, the company must allocate activities in an optimal manner.[7]

It is not sufficient to allocate these activities just to ensure that the operation is feasible since one of the primary objectives of the company is to operate at a profit.[8] Therefore, the company's objective would be to optimize profitability in accordance with company policies and the availability of resources.

The time span involved in planning the achievement of the company's objectives is a prime consideration. In a long term planning horizon the main considerations are what

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[7] Ibid., p. 77.

[8] Ibid., p. 77.

capital investments and policies are required and when, such that these in addition to existing resources will maximize the attainment of the company's objectives. The short term planning horizon is concerned with the best use of existing resources and policies.[9] The problem to be analyzed in this dissertation will be based on a short term planning horizon.

Because the whole of a system is not necessarily improved by optimizing one part or function of the system, emphasis on the allocation of activities in a function of an integrated system could result in suboptimization.[10] The problem, therefore, is to determine whether optimization of functions in Black Gold will result in suboptimization of profitability. The hypothesis is that for a short term planning horizon optimization of the integrated system at Black Gold will produce greater planned profitability than optimization of functions.

Because the level of activities in one subsystem is dependent upon the levels of activities in other subsystems, the optimization of a function constrains the optimizations of succeeding functions. Then, to optimize the whole system

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[9] W.J. Newby, "An Integrated Model of an Oil Company", published in Mathematical Model Building in Economics and Industry (New York: Hafner Publishing Company, 1968), p. 64.

[10] Peter F. Drucker, "Thinking Ahead: Potentials of Management Science", Harvard Business Review, 37 (January, 1959), p. 26.

by maximizing (or minimizing) functions or parts, any function must be optimized based on the constraints imposed by maximizing the proceeding parts. The profitability of an optimized non-integrated system is, therefore, the profit determined by optimizing the initial function plus the sum of the profits for each succeeding function optimized.

The capacity of a function may constrain the activities in other functions, therefore, operating at or near maximum output for a part or function would restrict the allocation of activities in another function. This restriction on the allocation of activities at or near capacity of a function could affect the maximum obtainable profitability of the integrated system. Therefore, to support or reject the hypothesis integrated and non-integrated optimization must be examined and compared at all capacity levels.

By comparing the profitability obtained by optimizing each combination of functions at each capacity level the best combination for maximizing profitability using non-integrated optimization can be determined for each output level. To support the hypothesis, the profitability determined by optimizing the integrated system must be greater than the profitability obtained from maximizing the profitability of the optimum combination of individual functions at each output level.

Theoretical Framework

A linear optimization model is a description of opera-

tions in mathematical terms and its purpose is the allocation of limited resources in an optimal manner in accordance with some goal or objective called an objective function.[11] The model consists of variables and constraints. Variables are activities such as the distillation of crude oil and constraints are limiting conditions such as capacity, product specifications, technical specifications and policy considerations on an operation.[12] The general form for a linear optimization model is as follows:

Maximize (or minimize) the objective function

$$(1\text{-}1) \qquad z = \sum_{j=1}^{n} c_j x_j$$

Subject to the constraints

$$(1\text{-}2) \qquad \sum_{j=1}^{n} a_{ij} x_j \geq (\text{or } \leq)\ b_i \quad \text{for } i=1,2,\ldots,n$$

and

$$(1\text{-}3) \qquad x_j \geq 0 \quad \text{for } j=1,2,\ldots,n$$

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[11] Frederick S. Hillier and Gerald J. Lieberman, Introduction to Operations Research (San Francisco, California: Holden-Day, Inc., 1967), p. 127.

[12] Norman J. Driebeek, Applied Linear Programming (Don Mills, Ontario: Addison-Wesley Publishing Co., Inc., 1969), pp. 19-21.

where a_{ij}, b_i, and c_j are constants and x_j represents the activity.

The limitations of a linear optimization model are proportionality, divisibility, additivity and finiteness. Proportionality is one of the primary requirements of linear programming and means that the objective function and all constraints must be linear. Proportionality also assumes that doubling the input of resources will double the output. Divisibility implies that any process may be operated at any positive level. If two processes are operated at levels x and y and the total output is x + y then the assumption of additivity is satisfied. For finiteness to be achieved the system being modeled must be finite.[13]

Black Gold's objective is to maximize profitability in accordance with company policies and resource limitations which is equivalent to maximizing profit subject to the constraints of company policies and resource availability. Since resource availability and company policies cannot be negative, then the operations can be described by a linear optimization model provided the limitations of the model are reasonable. The variables in the model include crude production and transportation options, refinery flexibility and product distribution alternatives. Resource constraints include technical specifications, capacity limitations and

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[13] Frederick S. Hillier and Gerald J. Lieberman, op. cit., pp. 135-38.

resource availabilities. Policy constraints include marketing policy which may determine demand, investment policy which could determine refinery flexibility or a resource availability and operating policy which could specify a minimum refinery operating level.

CHAPTER II

THE HYPOTHETICAL MODEL

Before the hypothetical model was constructed two constraints were imposed:

(1) The model must be a manageable size so that decomposition would not have to be used when optimizing the model.

(2) The maintenance of realism in the company operations so that the results would be meaningful.

In order to further simplify the construction of the model, the conversion processes for each refinery used in the model were made identical.

Black Gold is basically a domestic company and its vertically integrated operations are confined to the hypothetical territory depicted in Fig. 1. The company crude oil reserves are located in the three oil fields in the territory and the production of oil in the fields is subject to prorationing regulations. The gathering systems from the company oil wells to the batteries for distribution to the pipelines are maintained by Black Gold. One of the distribution pipelines is owned by the company and the others are operated by private transmission companies which charge a tariff for transporting the crude. The refineries, which are situated in the major market areas, can be supplied with domestic crude from the pipeline terminals or by

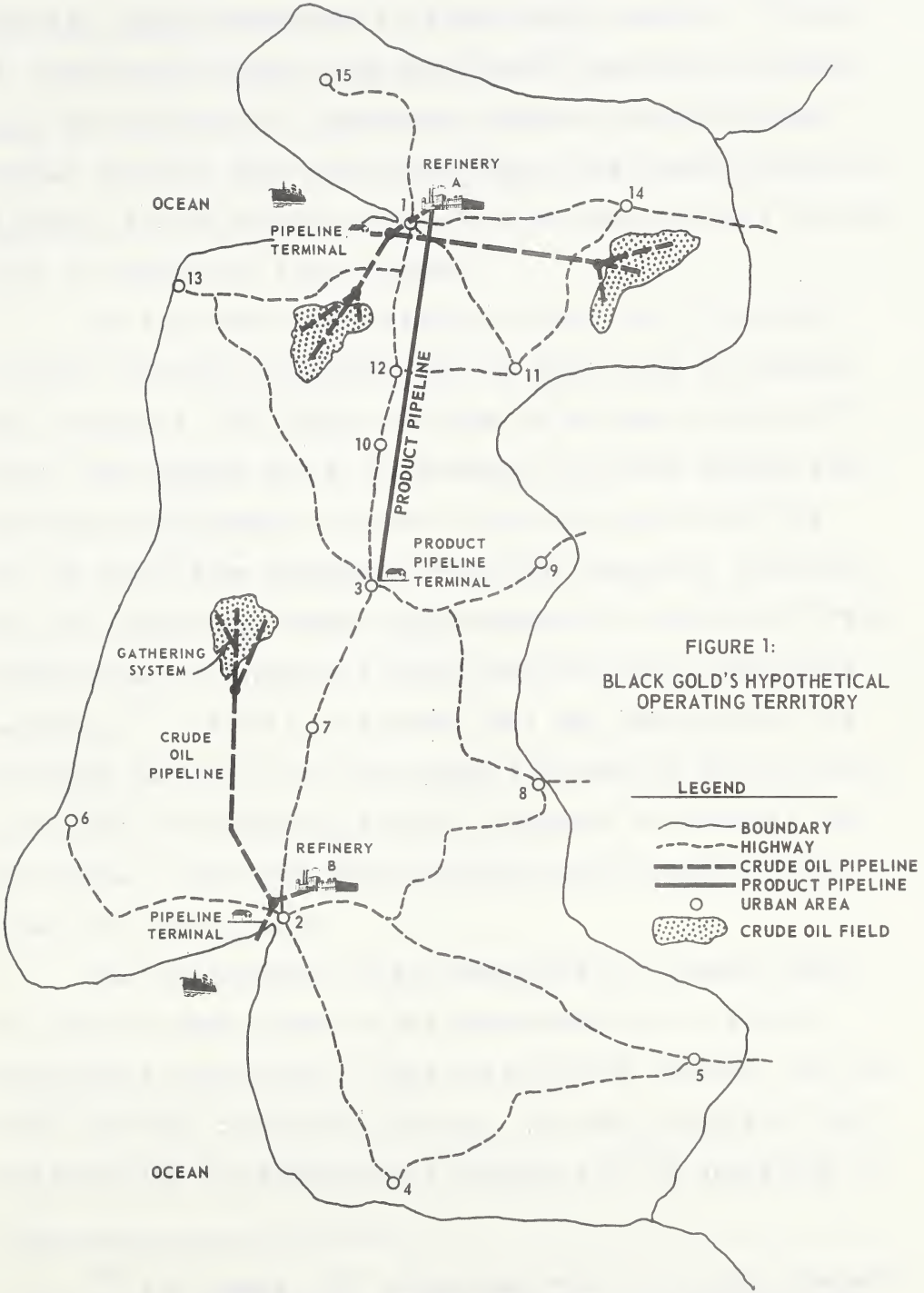

FIGURE 1:

BLACK GOLD'S HYPOTHETICAL OPERATING TERRITORY

foreign crude transported by transoceanic tankers. Crude is exported by tanker from the pipeline terminals located near the refineries. Processed products are distributed either directly from the refineries or the product pipeline terminal to the fifteen urban areas in the territory by company or commercial truck tankers.

For the short term planning horizon the allocation problem consists of determining how much crude to produce and transport, the supply of crude to be used in the refinery, the product mix to be produced, and what market each refinery will supply in order to optimize profitability. In the short term planning horizon the resources available to the company are known and the demand for products firmly established or capable of being predicted with reasonable accuracy.[14] It will be assumed that the time span of the planning period is of long enough duration so that the complication of scheduling partial shipments of products does not arise. The short term planning horizon used in this thesis is thirty days.

The construction of an integrated oil company model is further complicated by the nonconformity in various government regulations, crude distribution systems, and product mix from country to country. For the purpose of this dissertation the hypothetical company will be operating in

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[14] W.H. Newby, "An Integrated Model of an Oil Company", published in Mathematical Model Building in Economics and Industry (New York: Hafner Publishing Company, 1968), pp. 62-63.

an environment similar to the one in Canada.

Integrating crude production and distribution, refining and product distribution, the resulting matrix is as shown in Fig. 2 where the integrated objective function is the sum of the objective functions of each matrix.

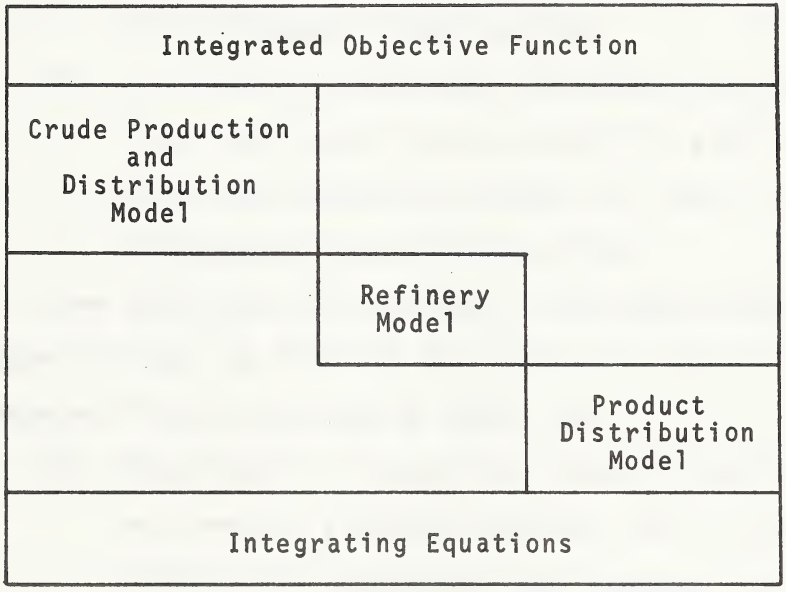

Fig. 2 Integrated Matrix

Assumptions and Limitations

The major assumptions inherent in the models in addition to the linear programming assumptions of additivity, proportionality and divisibility previously described are:

(1) The model is deterministic, i.e., demand is known with certainty.

(2) Storage facilities are adequate and the planning period is of long enough duration so that the complications of scheduling partial truck and tanker loads and of day-to-day inventory management do not arise.

(3) Product specifications are uniform in the markets so that the refineries can blend products without reference to destination.

(4) The models assume that the demand for products other than gasoline and diesel is sufficient to allow the company to market all these products produced at the weighted prices.

Some additional limitations in the model which were imposed in order to simplify and reduce the size of the integrated linear programming matrix are:

(1) Distribution alternatives from the refineries and product pipeline terminals are limited to 6,400 gallon commercial and company truck tankers.

(2) Weighted average prices and costs are used in the model to compensate for the error introduced by aggregating consumers into fifteen distribution points.

(3) The availability of foreign crude is limited to one type.

(4) Intermediate produce exchanges between refineries and finished product exchanges between companies are not included in the model.

The models used for integrated and non-integrated planning are identical. Therefore, the above assumptions and limitations should not affect the validity of the results since the purpose of the study is not to utilize the models for profit planning but to compare the differences in profitability from integrated and non-integrated planning. However, if integrated planning is found to be beneficial over a limited operating range, the limits of the range are subject to error.

Crude Production and Distribution Model

The company's crude production and distribution is subject to regulations.[15] Under prorationing regulations crude production allocations are dependent upon the total demand for all types of crude subject to the regulations, the recoverable reserves in an oil pool and the proratable acreage the company has leased in each oil pool. For each type of crude produced wellhead prices per unit volume of crude are posted. Pipeline legislation requires all pipeline facilities to distribute the crude production of all producers in the oilfields they service and regulates the tariff per unit volume the company can charge for transporting crude. Since all factors including demand are known in the short term planning horizon, the profitability of

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[15] The Alberta oil and gas conservation and pipeline regulations are used as a basis for constructing the model.

crude production and distribution is dependent only upon the prorationing system. Therefore, a change in the total usage of crude available within the prorationing system by the company refineries affect the profitability of crude production and distribution.

Because the demand for prorationed crude by consumers other than company refineries is exogenous to the integrated operations of the company, only the crude types demanded by company refineries are variables in the model. Thus, the variables for the crude production and allocation model are:

Q_{ir} where Q represents the total quantity of the i^{th} crude subject to prorationing regulations demanded monthly by the r^{th} company owned refinery

R_{ik} where R represents the total prorationed production of the i^{th} crude from the k^{th} oil pool

S_{ik} where S represents the prorated company production for the i^{th} crude from the k^{th} oil pool

Because the prorationing of crude is based on monthly demand, relationships between the demand of the company refineries and the allowable prorationed production exists for both oil pools and company production.[16] The formulas for determining R_{ik} and S_{ik} are:

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[16] The Alberta Oil and Gas Conservation Board formula is used to determine R_{ik} and S_{ik}.

$$(2\text{-}1) \qquad R_{ik} = \frac{(\sum_i \sum_r Q_{ir} + A)(U_{ik} - P_{ik}/2)}{(\sum_i \sum_k U_{ik} - \sum_i \sum_k P_{ik}/2)} \times F_{ik}$$

$$(2\text{-}2) \qquad S_{ik} = R_{ik}\ CPA_{ik}/TPA_{ik}$$

where A represents the total monthly demand for proratable crude by consumers other than the company refineries

CPA_{ik} represents the company proratable acreage for the i^{th} crude in the k^{th} pool

F_{ik} represents the pool performance factor for the i^{th} crude in the k^{th} pool

P_{ik} represents the cumulative production of the i^{th} crude in the k^{th} pool

TPA_{ik} represents the total proratable acreage for the i^{th} crude in the k^{th} pool

U_{ik} represents the ultimate reserves of the i^{th} crude in the k^{th} pool

Since the company objective is to maximize profits, the objective function is:

Maximize

$$(2\text{-}3) \qquad \sum_i \sum_k (rt_{ik} - ct_{ik})R_{ik} + \sum_i \sum_k (rp_{ik} - cp_{ik})S_{ik}$$

where cp = the company's variable costs of production

ct = the company's variable costs of distribution

rp = the revenue per unit volume of crude produced by the company

rt = the revenue per unit volume of crude distributed by the company pipeline

Since the allowable production from an oil pool is subject to maximum and minimum allowances then:

(2-4) $R_{ik} \leq$ maximum allowance for the i^{th} crude from the k^{th} pool

(2-5) $R_{ik} \geq$ minimum allowance for the i^{th} crude from the k^{th} pool

Because the gathering systems, truck pipelines and major distribution pipeline have maximum capacities, then:

(2-6) $\sum_{k} R_{ik} \leq$ gathering system capacity

(2-7) $\sum_{i} \sum_{k} R_{ik} \leq$ trunk pipeline capacity

(2-8) $\sum_{i} \sum_{k} R_{ik} \leq$ major distribution capacity

where i and k are summed only over values applicable to the appropriate capacity constraints

The linear program resulting from the substitution of data into the crude production and distribution model

is presented in Appendix A.

The Refinery Model

The functions of a refinery are: to separate the crude oil into various components; convert some of these components into more useful components; to upgrade and purify mixtures of various components; and to blend some of the components into end products such as gasoline and diesel fuel. A refinery is a flexible facility and the end product mix depends on the type of crude oils supplied to the distillation unit and the configuration of the refinery conversion units used to process the components and intermediate products. The distillation unit separates the crude oil into components such as butane, propane, naptha gasolines, distillate and gas oil. Conversion units include: catalytic cracking units which break up heavier hydrocarbons into lighter hydrocarbons; reforming units which upgrade the commercial quality of the naptha components of gasoline; alkylation units which form isoparaffins in the gasoline boiling range; and thermal coking units which reduce the residual bitumens from the distillation unit into carbon for fuel and anodes. The distillation and conversion units are designed so that the mix of intermediate products coming out of a process can be varied.[17] Fig. 3 depicts the process

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[17] Wickham Skinner and David C.D. Rogers, Manufacturing Policy in the Oil Industry (Homewood, Illinois: Richard D. Irwin, Inc., 1970), pp. 68-82.

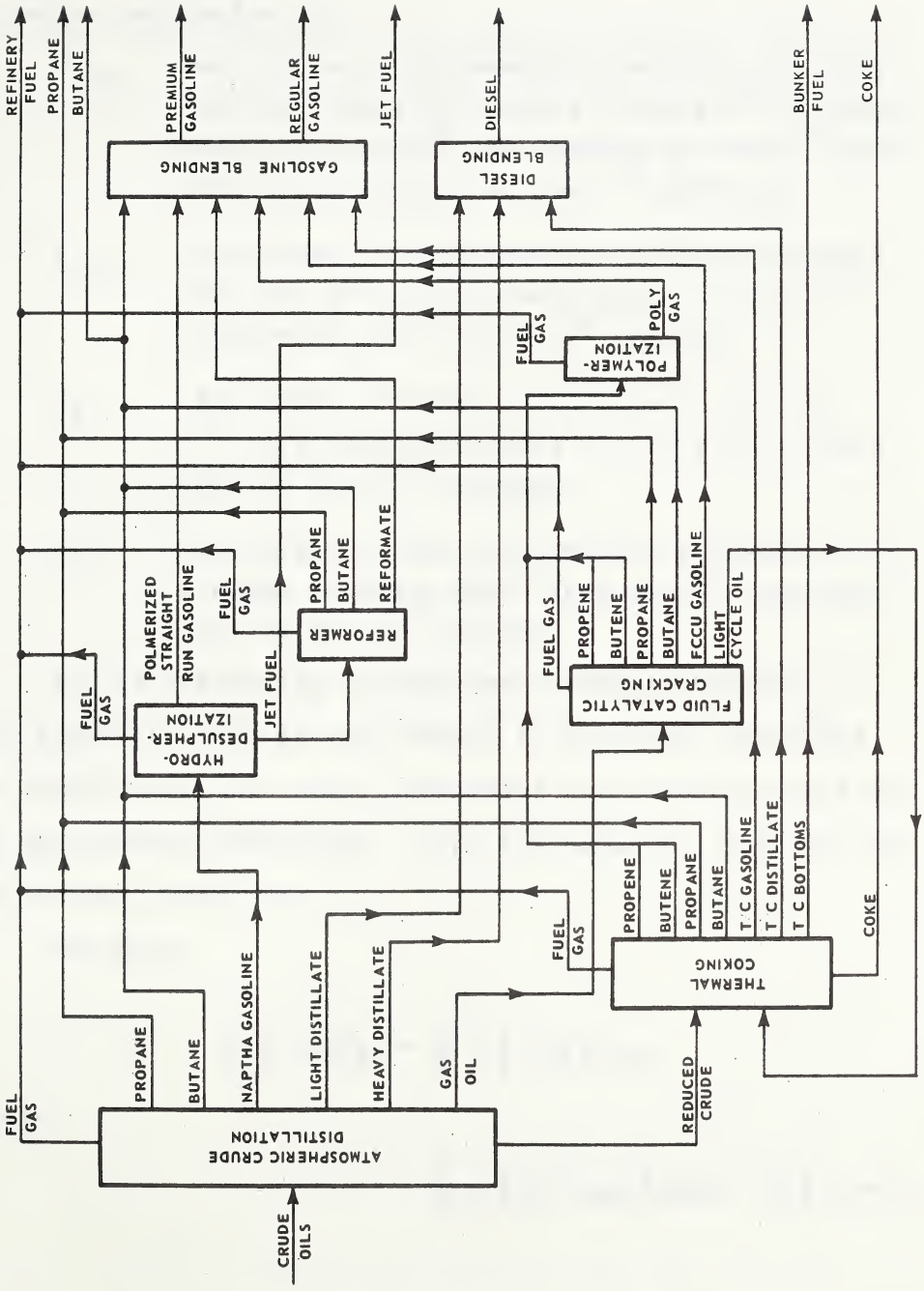

FIGURE 3: REFINERY PROCESS FLOWS

flows in the refineries.

The refinery model can be divided into five types of variables designated as:

B_{nmpr} - the volume of intermediate products entering into the blending process for the m^{th} blending stock for the n^{th} end product at the p^{th} additive concentration at the r^{th} refinery

$C_{\ell kr}$ - the volume of intermediate products entering into the ℓ^{th} conversion process in the k^{th} conversion unit at the r^{th} refinery

D_{jr} - the volume of crude which enters into the j^{th} distillation process at the distillation unit at the r^{th} refinery

P_{nr} - the volume of the intermediate products or blended products which form the n^{th} end product at the r^{th} refinery

In the processing of petroleum products revenue is only generated when an end product is marketed, therefore, the distillation of crude, conversion and blending functions are non-revenue generating. Thus the objective function for the refinery model is:

Maximize

$$- \sum_r \sum_j c_{jr} D_{jr} - \sum_r \sum_\ell \sum_k c_{\ell kr} C_{\ell kr}$$

(2-9)

$$- \sum_r \sum_n \sum_m \sum_p c_{nmpr} B_{nmpr} + \sum_r \sum_n r_{nr} P_{nr}$$

where the coefficient c represents the variable cost and r represents the revenue generated from the sale of the end product

The distillation of crude is constrained by the availability of crude oil types and the capacity of the system, therefore, the constraint equations for this process are:

(2-10) $\sum_j l_{ijr} D_{jr} \leq$ availability of the i^{th} crude at the r^{th} refinery

(2-11) $\sum_j D_{jr} \leq$ crude distillation capacity

The conversion units are limited by the volume of components and intermediate products available to be converted, the capacity of the unit and in some cases minimum operating levels. Assuming excess intermediate products can be disposed of by flaring, the constraint equations for conversion are as follows:

(2-12) $$\sum_j a_{ijr} D_{jr} + \sum_{k-1} \sum_{\ell} a_{i\ell kr} C_{\ell kr} \geq \sum l_{i\ell kr} C_{\ell kr}$$

for the i^{th} component from the distillation and other conversion units at the r^{th} refinery

(2-13) $\sum_{\ell} C_{\ell kr} \leq$ conversion unit capacity for the k^{th} conversion process at the r^{th} refinery

(2-14) $\sum_{\ell} C_{\ell kr} \geq$ minimum operating level for the k^{th} conversion process at the r^{th} refinery

where a represents the yield or technical coefficient of the component or intermediate product in the process in which the product was produced

Blending is constrained by the availability of components and intermediate products used in the blending of an end product and the end product specifications. Writing the availability equations in linear programming format:

$$(2\text{-}15) \qquad \sum_j a_{mjr} D_{jr} + \sum_k \sum_\ell a_{m\ell kr} C_{\ell kr} \geq \sum_n \sum_p {}^{1}_{nmpr} B_{nmpr}$$

for the m^{th} component from the distillation and conversion units for the m^{th} blending stock at the r^{th} refinery

Since the sum of the volume of the blended stocks or components for an end product equals the volume of the n^{th} end product:

$$(2\text{-}16) \qquad \sum_j a_{njr} D_{jr} + \sum_\ell \sum_k a_{n\ell kr} C_{\ell kr} = P_{nr}$$

and

$$(2\text{-}17) \qquad \sum_m \sum_p B_{mnpr} = P_{nr}$$

All the important properties in the product specifications blend linearly on the basis of volume except tetraethyl lead (TEL) which is added to increase the octane number

of gasoline blends.[18] The blending of TEL has two phases: the relationship between the octane number and the TEL concentration in a blending stock; and the octane numbers of each blending stock. As the concentration of TEL is increased for a particular blending stock the octane number increases at a decreasing rate as shown in Fig. 4.

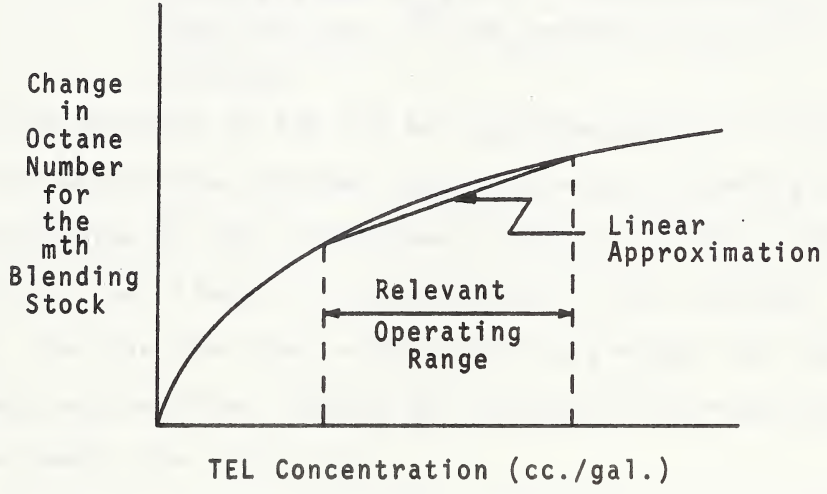
Change in Octane Number for the mth Blending Stock
Linear Approximation
Relevant Operating Range
TEL Concentration (cc./gal.)

Fig. 4 TEL Concentration vs. Octane Number

This type of constraint can be programmed into a linear programming model by representing the curve as a straight line approximation in the relevant operating range as shown

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[18] W.W. Garwin et al., "Applications of Linear Programming in the Oil Industry", Management Science, 3 (July, 1957), p. 417.

in Fig. 4.

For the second phase of blending, the final octane number can be calculated by using the weighted average octane number of the components. This method appears satisfactory for many stocks.[19]

In order to express the blending of TEL in linear programming form let:

ON_{nmpr} - be the octane number of the m^{th} blending stock blended at the p^{th} concentration level for the n^{th} end product at the r^{th} refinery

Since the addition of TEL can be approximated by a linear equation within the relevant operating range, blending can be represented by the simultaneous addition of TEL at the upper and lower limits of concentration in the relevant range. Because the final octane must be greater than the minimum required then letting ON_n represent the required octane number the result is:

$$\sum_m \sum_p ON_{nmpr} B_{nmpr} \geq ON_{nr} P_{nr} \tag{2-18}$$

where p represents the upper and lower limit of TEL concentration in the relevant operating range

For the other properties required in the product specifications which blend linearly on the basis of volume

---

[19] Alan S. Manne, Scheduling of Petroleum Refinery Operations (Cambridge, Massachusetts: Harvard University Press, 1956), p. 77.

the linear equations are:

$$(2\text{-}19) \qquad \sum_m \sum_p b_{tnmpr} B_{nmpr} \geq b_{tnr} P_{nr}$$

or

$$(2\text{-}20) \qquad \sum_{mp} \sum b_{tnmpr} B_{nmpr} \leq b_{tnr} P_{nr}$$

where b_{tnmp} is the t^{th} property of the m^{th} blending stock at the p^{th} additive concentration level used to produce the n^{th} end product and b_{tn} is the desired t^{th} property of the n^{th} end product at the r^{th} refinery

Finally the volume of the end product formed must be equal to demand because of limited storage facilities or:

$$(2\text{-}21) \qquad \sum_r P_{nr} = \text{demand for the } n^{th} \text{ product}$$

Since one of the components formed during distillation and conversion is used for the internal fuel requirements of the units in the refinery, then the volume of fuel gas formed is:

$$(2\text{-}22) \qquad \sum_j a_{1jr} D_{jr} + \sum_\ell \sum_k a_{1\ell kr} C_{\ell kr}$$

where a_{1jr} and $a_{1\ell kr}$ represent the yield of fuel gas from the distillation and conversion units at the r^{th} refinery

Letting e_{jr} and $e_{\ell kr}$ be the volume of fuel gas required for unit of volume of input to each process then:

$$(2\text{-}23) \qquad \sum_{j} (a_{1jr} - e_{jr})D_{jr} + \sum_{\ell} \sum_{k} (a_{1\ell kr} - e_{\ell kr})C_{\ell kr} \geq 0$$

The linear program resulting from substituting data into the refinery equations is presented in Appendix B (see folder). The relevant product specifications for blending are presented in Appendix C.

Product Distribution Model

The distribution system used by Black Gold to market gasoline and diesel from the refinery and product pipeline terminals is illustrated in Fig. 5. All other products are sold f.o.b. the refineries and are shipped by the customer or commercial transportation companies.

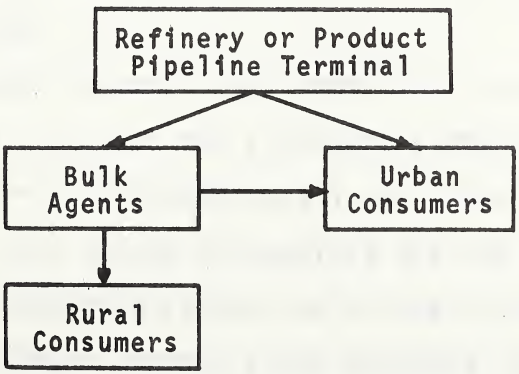

Fig. 5 Distribution System

Direct shipments by commercial or company truck tankers are made from the refinery and product pipeline terminals to bulk agents and high volume urban consumers. The bulk agents, which are located in the urban areas, supply all other urban consumers and rural customers.

The bulk agents and retail outlets lease their facilities at a fixed rate from the company and receive commissions based on the volume of products sold. Other consumers either provide their own storage and handling facilities or lease them from the company. Thus the only variable costs for the short term planning horizon are product pipeline costs and commissions which vary with respect to volume and truck tanker costs which depend upon the routes and types of units utilized. Since retail outlet commissions are based on demand which is determinate in the short term planning horizon, the product distribution model is reduced to the allocation of distribution alternatives from the refinery and product pipeline terminals in order to maximize profitability.

In order to reduce the complexity of the distribution and pricing structure the following simplifications are made:

(1) Price differentials in an urban area resulting from volume discounting and the competitive tendering system can be approximated using a single product price weighted in proportion to volume.

(2) Direct shipments to consumers and bulk agents can be represented as a single point by aggregating demand in the area and weighting truck tanker costs from each refinery and product pipeline terminal in proportion to the volume distributed to each delivery destination.

Letting Y_{nrjk} represent the volume of product n shipped from refinery r to product pipeline terminal j for distribution to delivery point k and Y_{nrk} represent the volume of product n shipped from refinery r for distribution directly to delivery point k, then the volume of each product delivered to the area must equal the total demand for product n at k. Therefore, the equation is:

$$\text{(2-24)} \quad \sum_r \sum_j Y_{nrjk} + \sum_r Y_{nrk} = \text{total demand for product n at delivery point k } (D_{nk})$$

Because all deliveries originate from the refineries, then, the volume of product n shipped from the refineries must equal total demand. This equation is:

$$\text{(2-25)} \quad \sum_r \sum_j \sum_k Y_{nrjk} + \sum_r \sum_k Y_{nrk} = \sum_k D_{nk}$$

Since the volume of product n produced at refinery r must be greater than the volume shipped from the refinery then:

$$(2\text{-}26) \qquad \sum_j \sum_k Y_{nrjk} + \sum_k Y_{nrk} \leq S_{nr}$$

where S_{nr} denotes the supply of product n from refinery r

Because the supply of the refineries is limited by their capacity then:

$$(2\text{-}27) \qquad S_{nr} = \text{capacity for producing product n at refinery r}$$

If X_{rkus} and X_{jkus} represent the number of shipments from refinery r to delivery point k using a u type unit with delivery method s and the number of shipments from product pipeline terminal j to delivery point k using a u type unit with delivery method s respectively, then letting g_{us} represent the capacity of a u type unit using delivery method s it must be specified that:

$$(2\text{-}28) \qquad \sum_n \sum_r Y_{nrjk} \leq \sum_s \sum_u g_{us} X_{jkus}$$

and

$$(2\text{-}29) \qquad \sum_n Y_{nrk} \leq \sum_s \sum_u g_{us} X_{rkus}$$

This insures that enough trips are made by each type of unit using delivery method s to supply the delivery routes.

If h_{rkus} and h_{jkus} denote the time to travel each r to j and j to k route for a u type delivery unit using delivery method s and h_{us} and n_{us} denote the maximum time a u type unit can be used during the time period and the number of units available respectively, then:

$$\sum_{k} h_{rkus} X_{rkus} \leq h_{us} n_{rus} \tag{2-30}$$

and

$$\sum_{k} h_{jkus} X_{jkus} \leq h_{us} n_{jus} \tag{2-31}$$

Because revenues, commissions and pipelines costs are dependent on volume and road transportation costs are a function of the number of trips required to supply each route then the objective function is:

Maximize

$$\sum_{r}\sum_{n}\sum_{j}\sum_{k} (r_{nrjk} - c_{nrjk}) Y_{nrjk} + \sum_{r}\sum_{n}\sum_{k} (r_{nrk} - c_{nrk}) Y_{nrk} - \sum_{r}\sum_{k}\sum_{s}\sum_{u} c_{rkus} X_{rkus} - \sum_{j}\sum_{k}\sum_{s}\sum_{u} c_{jkus} X_{jkus} \tag{2-32}$$

where the coefficient r represents the revenue per unit volume or trip and c the variable cost per unit volume or trip

Appendix D contains the linear program resulting from substituting data into the product distribution model (see folder).

Integrating Equations

The total quantity of the i^{th} crude type processed by the r^{th} refinery is

(2-33) $$\sum_j l_{ijr} D_{jr}$$

where D_j represents the volume of crude entering into the j^{th} distillation process

Therefore, the total quantity of a crude type demanded by a refinery is:

(2-34) $$\sum_j l_{ijr} D_{jr} = Q_{ir}$$

where Q_{ir} is the quantity of the i^{th} crude demanded by the r^{th} company refinery

Because the prorated crude production is dependent on the quantity of a crude type demanded by company refineries, this equation integrates the crude production and distribution model with the refinery model.

The availability of a prorated crude type is determined in the crude production and distribution models thus equation (2-10) in the refinery model is redundant for crude types subject to prorationing. The integration of refining and crude production and distribution, therefore, only requires changing of the inequality to an equality and substituting Q_{ir} into the right-hand side of equation (2-10) for crude

types available under prorationing in the crude production and distribution model.

The volume of intermediate and blended products which form the n^{th} end product at the r^{th} refinery (P_{nr}) equals the supply of product n from refinery r (S_{nr}) in the product distribution model, therefore, the integration of refining and product distribution can be accomplished by substituting P_{nr} for S_{nr} in the product distribution model equation (2-26):

$$\sum_j \sum_k Y_{nrjk} + \sum_k Y_{nrk} \leq P_{nr} \qquad (2\text{-}35)$$

However, since storage space is limited, the volume of blended products can only exceed the supply for distribution in the very short run. Therefore, the inequality must be changed to an equality and the integrating equation becomes:

$$\sum_j \sum_k Y_{nrjk} + \sum_k Y_{nrk} = P_{nr} \qquad (2\text{-}36)$$

Sources of Data

Much of the data for the models was supplied by the petroleum industry and for proprietary reasons sources must remain anonymous. Many of the constraints were selected after initial computer runs in order to make the model realistic. The constants in the crude production and distribution model were estimated on the basis of information

prepared by the Alberta Oil and Gas Conservation Board and the petroleum industry.

CHAPTER III

ANALYSIS AND CONCLUSIONS

Method of Analysis

To support the hypothesis, integrated and functional planning must be examined and compared at all capacity levels, therefore, the total gasoline demand was varied from 300,000 barrels to maximum capacity per planning period in increments of 30,000 barrels for both demand vectors used in the analysis. The two demand vectors which are designated as vector A and vector B are presented in Appendix E. Although the vectors are hypothetical, the product mix is based on current Alberta refinery runs. The premium and regular gasoline product mix of 30 per cent premium and 70 per cent regular is the same in both vectors, however, diesel demand in vectors A and B is varied from 50 per cent to 70 per cent of total gasoline demand in vectors A and B respectively. The demand for these products in each consumption center is assumed to be proportionate to the total volume of gasoline demanded.

The functional planning stragegies evaluated in the initial analysis are shown in Table 1. The general procedure used to evaluate each functional planning strategy was to maximize the profitability for the initial function for a specified product demand level then to optimize the profitability of each successive function based on the constraints imposed by all preceding functions optimized.

TABLE 1

FUNCTIONAL PLANNING STRATEGIES

Functional Planning Strategy	Initial Function Optimized	Second Function Optimized	Third Function Optimized
1	Distribution	Refining	Crude Production and Distribution
2	Refining	Crude Production and Distribution	Product Distribution
3	Crude Production and Distribution	Product Distribution	Refining
4	Crude Production and Distribution	Refining	Product Distribution

Referring to Table 1, consider, for example, optimizing the profitability for functional planning strategy 1. The product distribution model is initially optimized for a given demand vector and demand level. Since the refineries must produce gasoline and diesel in specific quantities in order to optimize the profitability of product distribution, the volumes of premium and regular gasoline and diesel allocated to each refinery by the optimized product distribution model are programmed into the refinery model as demand constraints and this function is then optimized. Because specific crude allocations are required in order to optimize profitability of the preceding function optimized, the next step is to program the allocations of crudes from the optimized refinery model into the crude production and distribution model and then optimize this function. The total profitability is then determined by adding the profitabilities determined by the successive optimization of each function.

Prorationing is based on the volume of crude reserves and the capability to produce in the oil field, therefore, in the optimized crude production and distribution model the maximum profitability should be independent of the types of domestic crudes demanded by the refineries provided the total remains constant. This was confirmed by the presence of alternative optima when the crude production and distribution model was optimized for a given domestic crude demand. Therefore, in order to eliminate the undesirability of

alternate optima when crude production and distribution is the initial function optimized, the refining and product distribution functions were optimized subject to utilizing the maximum volume of domestic crude.

Because there are alternative methods of processing products in the refineries, more than one optimum solution could exist at a given gasoline and diesel demand. This was substantiated when the refinery model was optimized. However, in the analysis alternative optima were initially ignored because:

(1) The production of one product from one refinery could not be shifted to another without causing a complete reallocation of processing operations.

(2) If the results showed that the best functional planning strategy is subject to changes in total profitability due to the presence of alternate optima then the next best functional planning strategy may not be subject to changes in total profitability due to the presence of alternate optima, therefore, all alternate optima would not have to be explored since at least one alternate solution may provide greater planned profitability.

When the product distribution model was maximized alternate optima were not present. Therefore, alternate optima do not affect the total profitability when the product distribution model is optimized subject to maximum

domestic crude utilization because:

(1) The refinery outputs are constrained by product distribution model optimal allocations.

(2) The refinery inputs are constrained to maximum domestic crude utilization.

However, in all the other functional planning strategies evaluated the total profitability would be affected by alternate optima because the refinery inputs and outputs are not simultaneously constrained.

The results of the initial analysis showed that no one functional planning strategy was best when the alternate optima were ignored, therefore, a method of analyzing alternate solutions was needed. Only one of the two best functional planning strategies was subject to changes in total profitability due to the presence of alternate optima. Therefore, if it could be proven that one of the alternate optima provided greater planned profitability than for the planning strategy not subject to changes in total profitability due to the presence of alternate optima, the method of analyzing alternate optima would not have to produce the maximum total profitability. The integrated model allocations showed that the volume of gasoline and diesel produced at refinery B was greater than the volume of these products produced in the refinery when the refineries were optimized subject to maximum domestic crude utilization for these demand levels. Therefore, the method used was to maximize the volume of products produced in refinery B sub-

ject to the maximum profitability found in the initial analysis as well as maximum domestic crude utilization. The product distribution model was then reoptimized using the allocations of gasoline and diesel in each refinery determined by maximizing the volume of products produced at refinery B. Since the results confirmed that the alternate solution using this method provided greater planned profitability, a further analysis of alternate optima was not needed to establish the best functional planning strategy.

Since fixing the availability of company truck tankers is unrealistic for such a wide range in demand, it was assumed that enough company truck tankers were available to distribute the products in the initial analysis. The effects of a shortage of company truck tankers were investigated after the initial analysis was completed. The procedure used to reduce the total truck availability at each refinery and product pipeline terminal was to decrease the total number of trucks at each location in the optimal solutions in the sequence of utilization starting with the lowest utilized unit and repeating the cycle.

Because the best functional planning strategy was subject to changes in total profitability due to the presence of alternate optima, the total profitability cannot be compared directly to test the hypothesis since all alternate optima were not generated in the analysis. However, the value of the refinery objective function is unique. Thus, if the total refinery profitability from the integrated

analysis is equal to the total refinery profitability from the best functional planning strategy at a particular demand level, then there must be an alternative refinery optimum where the allocations of inputs and outputs using this functional planning strategy equal the input and output allocations of the refineries in the integrated analysis. If the allocations of crude in the refineries in functional and integrated planning are identical and the crude production and distribution function is separated into a subprogram, the subprogram and the crude production and distribution model used for functional planning are identical and therefore must have identical optimal profitabilities. The product distribution function optimal profitabilities for integrated and functional planning are also the same if the refinery outputs are the same for both types of planning since the product distribution subprogram in the integrated model and the product distribution model used for functional planning are identical. Therefore, the total profitabilities using the integrated and functional planning strategies must be equal at the demand levels where the refinery profitabilities for the two strategies are equal. The hypothesis was tested using this method because the best functional planning strategy was subject to changes in total profitability due to the presence of alternate optima and all alternate solutions were not generated.

The Preliminary Analysis

The addition of tetra-ethyl lead to gasoline blending stocks in the refinery models was approximated by using a linear function over a relevant range. Because the relevant ranges to be used at each gasoline demand level in the refineries were unknown prior to the start of the analysis, the purpose of the preliminary analysis was to determine an approximate relevant range for the analysis at each demand level. The procedure used was to optimize the refineries at several demand levels using the maximum upper limit for tetra-ethyl lead addition of 3.6 c.c./gal. and the minimum lower limit of 0 c.c./gal. The results of the computer runs indicated that intermediate concentration levels would not occur frequently for the demands to be used in the analysis. Therefore, rather than using a number of relevant ranges for each demand level, a single range of 0 to 3.6 c.c./gal. was used to simplify the models. The results of the analysis confirmed that relatively few intermediate concentration levels would occur and rather than re-analyze the solutions where this occurred it was assumed that the magnitude of error introduced would not significantly affect the results.

The Initial Analysis

The results of determining the planned profitabilities of integrated and functional planning are shown in Tables 2 and 3. These results show that the two best functional

TABLE 2

PLANNED PROFITABILITIES USING DEMAND VECTOR A

Gasoline Demand	Profitability Integrated Planning	Profitability for Planning Strategy[a]			
		4	3	2	1
300,000	5,452,145.54	5,433,155.27	5,431,405.36	5,289,736.54	5,280,211.07
330,000	5,651,118.77	5,640,110.65	5,631,352.79	5,460,450.17	5,462,630.34
360,000	5,849,085.94	5,842,789.92	5,782,900.27	5,629,478.70	5,429,033.75
390,000	6,045,934.15	6,036,425.26	5,862,316.84	5,796,543.80	5,461,027.95
420,000	6,223,950.75	6,208,673.85	6,059,459.26	5,962,832.68	5,629,423.50
450,000	6,392,505.51	6,389,054.56	6,239,025.34	6,119,755.46	5,797,330.30
480,000	6,492,505.69	6,485,368.87	6,402,499.33	6,036,196.19	5,944,732.48
508,888.06	5,781,633.74	5,781,556.31	5,781,497.12	5,781,556.31	5,781,497.12

[a] See Table 1 for an explanation of planning strategies.

TABLE 3

PLANNED PROFITABILITIES USING DEMAND VECTOR B

Gasoline Demand	Profitability Integrated Planning	Profitability for Planning Strategy[a]			
		4	3	2	1
300,000	5,839,149.30	5,824,336.63	5,750,785.64	5,601,041.05	5,407,661.14
330,000	6,053,404.37	6,049,476.28	5,952,531.52	5,798,718.63	5,544,624.36
360,000	6,257,674.99	6,252,534.53	6,076,682.71	5,995,729.87	5,651,699.38
390,000	6,420,875.07	6,415,487.06	6,263,959.33	5,981,306.99	5,810,634.18
420,000	6,541,432.20	6,541,375.47	6,396,259.20	6,091,239.55	5,994,469.40
450,000	6,167,500.66	6,166,998.14	6,167,199.44	6,011,825.03	6,002,927.91
451,880.32	5,890,633.97	5,889,835.67	5,890,332.63	5,889,835.67	5,890,332.63

[a] See Table 1 for an explanation of planning strategies.

planning strategies are 3 which is the same as initially maximizing the profitability of the refining function subject to maximum domestic crude utilization and 4 which is the same as initially maximizing the profitability of the distribution function subject to maximum domestic crude utilization. In addition, optimizing the refinery subject to maximum utilization of domestic crude provided greater planned profitability at all gasoline demand levels except 450,000 and 451,880.32 barrels per planning period using demand vector B.

Because the presence of alternate optima affect total profitability when the refineries are optimized subject to maximum domestic crude utilization at these two demand levels, a further analysis was conducted to determine whether the total planned profitability could be increased by using other alternate optimal solutions. The results of this analysis are presented in Table 4. These results show that the best strategy for Black Gold is to optimize the refinery subject to maximum domestic crude utilization when planning is done on a functional basis since this strategy provides greater planned profitability at all demand levels for each demand vector.

The Sensitivity of Functional Planning to the Availability of Truck Tankers

The number of company trucks was unlimited in the initial analysis, therefore, the effect of a limited truck fleet was analyzed next. The reasons for this analysis are:

TABLE 4

REVISED TOTAL PROFITABILITIES
USING ALTERNATE OPTIMA

Gasoline Demand Using Vector B	Profitability for Planning Strategy	
	4	3
450,000.00	6,167,500.67	6,167,199.44
451,880.32	5,890,633.19	5,890,332.63

(1) The optimal functional planning strategy may change if the total profitability is sensitive to the costs of distribution.

(2) The allocations of truck tankers can vary for each function combination optimized as shown in Table 5. Therefore, equalizing the total number of trucks available could have an effect on the best functional planning strategy.

The demand level of 300,000 barrels per planning period using demand vector A was used in order to test the sensitivity of the model to the availability of trucks because the most likely change in functional planning strategy would occur where the difference between optimizing the refineries and product distribution subject to maximum crude utilization is minimal. These results show that the optimal planning strategy is insensitive to the costs of distribution since the differences in profitability presented in Table 6 are relatively constant for each size of truck fleet analyzed. In addition, the effects of equalizing the total number of trucks available for each function combination will not have an effect on the optimal planning strategy because a reduction in the total truck fleet of three units, which is greater than the maximum difference in truck allocations, reduces the difference in profitability less than the minimum differences in profitability between the two best functional planning strategies for all cases shown in Table 5 where the total truck allocations are unequal.

TABLE 5

OPTIMAL ALLOCATIONS OF TRUCK TANKERS

Gasoline Demand	Truck Tanker Allocations			
	Planning Strategy Demand Vector A		Planning Strategy Demand Vector B	
	4	3	4	3
300,000	18	17	21	19
330,000	19	19	21	20
360,000	21	21	23	23
390,000	23	22	25	25
420,000	25	23	27	27
450,000	26	25	28	28
480,000	27	27	-	-
Maximum Capacity	28	28	28	28

TABLE 6

THE EFFECTS OF REDUCING COMPANY
TRUCK TANKER FLEET

Total Truck Fleet	Total Profitability for Planning Strategy		Difference in Profitability
	4	3	4-3
18	5,433,155.27	5,431,405.36	1,749.91
17	5,433,155.22	5,431,405.36	1,749.86
16	5,432,915.09	5,431,405.32	1,509.77
15	5,431,891.09	5,430,703.26	1,187.86
14	5,430,983.51	5,428,681.31	2,302.20
13	5,429,514.89	5,427,691.83	1,832.06
12	5,428,295.84	5,426,497.87	1,797.97

The Analysis of Integrated and Functional Planning

For the best functional planning strategy and integrated planning the differences in refinery profitability are presented in Table 7. Differences in refinery profitability only occur at gasoline demand levels of less than 450,000 and 330,000 to 390,000 barrels per planning period for demand vectors A and B respectively, therefore, the hypothesis is only supported at these demand levels. Although the differences in profitability where the hypothesis is supported could probably be reduced by using other alternate refinery optima in the best functional planning strategy, the differences in profitability which are shown in Table 8 appear to be substantial enough to justify using an integrated planning strategy over a functional planning strategy. The differences indicate that greater than 10 per cent in profitability could be gained by using integrated planning if the best functional planning strategy was previously employed at Black Gold.

Comparing the optimal allocations of crude for the integrated analysis to the allocations determined by using the best functional planning strategy, the results presented in Table 9 show that domestic crude utilization was not maximized at all demand levels in the integrated analysis. The utilization of domestic crudes is maximized in the best functional planning strategy, therefore, the utilization of foreign crudes must be minimized. Since foreign crude allocations in the integrated model are the same as in the best

TABLE 7

REFINERY PROFITABILITIES FROM INTEGRATED AND FUNCTIONAL PLANNING

Gasoline Demand	Refinery Profitabilities for Demand Vector			
	A		B	
	Integrated Model	Planning Strategy 4	Integrated Model	Planning Strategy 4
300,000	221,488.43	113,810.16	329,982.29	329,982.29
330,000	255,186.44	183,668.17	388,469.68	388,780.83
360,000	273,683.14	246,283.15	436,183.39	436,305.49
390,000	304,354.48	304,825.93	443,878.59	444,286.83
420,000	346,376.75	346,830.59	411,507.01	411,507.01
450,000	379,957.09	380,277.12	117,801.62	117,801.62
480,000	337,741.03	337,741.03	-	-
Maximum Capacity	7,602.77	7,602.77	101,391.98	101,391.98

TABLE 8

DIFFERENCES IN TOTAL PROFITABILITY BETWEEN INTEGRATED AND FUNCTIONAL PLANNING

Gasoline Demand	Differences in Planned Profitability for			
	Demand Vector A		Demand Vector B	
	Absolute	Percent[a]	Absolute	Percent[a]
300,000	18,990.27	93.1	0.0	0.0
330,000	11,008.12	49.2	3,928.09	14.9
360,000	6,296.02	25.8	5,140.46	18.1
390,000	9,508.18	17.1	5,338.01	17.9
420,000	15,276.90	54.3	0.0	0.0
450,000	3,450.95	11.6	0.0	0.0
480,000	0.0	0.0	-	-
Maximum Capacity	0.0	0.0	0.0	0.0

[a] The percentage differences were calculated on the basis of the absolute change divided by the total integrated profitability minus the profitability derived from crude exported which is $3,412,815.12.

TABLE 9

CRUDE ALLOCATIONS FOR INTEGRATED AND FUNCTIONAL PLANNING

Gasoline Demand	Crude Allocations							
	Demand Vector A				Demand Vector B			
	Integrated Planning		Planning Strategy 4		Integrated Planning		Planning Strategy 4	
	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign	Domestic	Foreign
300,000	731,569		900,000		900,000		900,000	
330,000	776,911		900,000		900,000		900,000	
360,000	849,666		900,000		900,000		900,000	
390,000	900,000		900,000		900,000		900,000	
420,000	900,000		900,000		900,000		900,000	
450,000	900,000		900,000		474,674	425,326	474,674	425,326
480,000	900,000		900,000		-	-	-	-
Maximum Capacity		900,000		900,000		900,000		900,000

functional planning strategy, this implies that the utilization of foreign crudes is also minimized in the integrated model. Because domestic crude allocations are not maximized and foreign crude allocations appear to be minimized in the integrated model, a better non-integrated strategy appears to be to maximize refinery profitability subject to minimum utilization of foreign crudes. Long-run misallocations of resources would also be reduced using this planning strategy because more efficient allocations of domestic crude would result.

Conclusions and Implications

Because systems vary from nation to nation and from one integrated oil company to another, the significance of this study to the oil industry is difficult to extrapolate and all generalizations to the industry must be considered very tentative. However, emphasizing the allocation of activities in functions of an integrated petroleum company does appear to result in suboptimization of profitability which could significantly reduce total potential profitability. The difference in total profitability between integrated and functional planning in this study appeared to be in excess of 10 per cent for operating ranges where integrated planning was found to be superior to functional planning.

The best functional planning strategy evaluated was to initially maximize the profitability for crude production and distribution, then to optimize profitability for the

refineries and finally to optimize the profitability of product distribution. However, comparing the allocations of crudes in the integrated model and the best functional planning strategy misallocations of domestic crude utilization occurred at the lower demand levels used in the analysis. Since foreign crude allocations appeared to be minimized in the integrated model, maximizing the refining profitability subject to minimizing the allocations of foreign crudes in the refineries then optimizing crude production and distribution and product distribution could possibly be a superior non-integrated planning strategy.

Optimizing refinery profitability subject to minimization of foreign crude usage initially would probably reduce the difference in profitability between integrated and non-integrated planning at demand levels where the suboptimal usage of domestic crude occurs. However, at demand levels where suboptimal usage of crude does not occur this planning strategy would not be expected to provide greater non-integrated planned profitability. If the results using this decision rule showed that domestic crude is maximized, the decision model is equivalent to the best functional planning strategy and hence gives the same total profitability for demand levels where crude suboptimization does not occur. Integrated planning also maximizes domestic crude usage at these demand levels. Therefore, if domestic crude utilization is not maximized for these demand levels when optimizing the refinery subject to minimum foreign crude utilization,

suboptimization of profitability must occur. Thus optimization using this non-integrated planning strategy must occur and it would probably only provide a significant improvement in the difference between integrated and non-integrated planning at demand levels where domestic crude allocations are suboptimized.

The planning strategies did not appear to be sensitive to a shortage of truck tankers in the analysis, however, the reduction in profitability due to the shortage of a truck that could be fully utilized could be significant. The reduction in total profitability per unit which could be fully utilized is in the order of $1,000 per thirty days which could significantly alter long term profitability.

Suggestions for Further Research

The operations of a vertically integrated oil company have been simplified through the construction of a hypothetical company, therefore, further research is required in order to establish the degree of suboptimization that occurs by using non-integrated planning. Additional research is required in evaluating non-integrated planning strategies since only functional planning strategies were thoroughly investigated in this study.

Functional planning is dependent on the prices used for intrafunctional transfers of products. Although the transfer prices used in the model were based on actual prices, the sensitivity of functional planning to changes

in them has not been explored in the analysis. The use of different transfer prices could lead to better resource allocation in functional planning and reduce the difference in total profitability between integrated and non-integrated planning. Therefore, further research is required in this area.

Integrated petroleum operations may be subject to greater demand restrictions than were used in this analysis. Although additional demand restrictions would reduce refinery flexibility and hence be expected to reduce the difference in total profitability between integrated and functional planning, the effects of this were not investigated. Therefore, the effects of further demand constraints should be examined in future analyses of integrated petroleum operations.

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APPENDICES

APPENDIX A

CRUDE PRODUCTION AND DISTRIBUTION MODEL

		REFINERY ALLOCATIONS			POOL ALLOCATIONS						COMPANY ALLOCATIONS					
OBJECTIVE ROW		0.0	0.0	0.0	0.0	0.0	0.0	.15	.15	0.0	2.18	2.20	2.21	2.14	2.14	2.00
REFINERY DEMANDS	CRUDE 1 =	1.0														
	CRUDE 2 =		1.0													
	CRUDE 4 =			1.0												
POOL PRORATIONS	520800. =	-.0868	-.0868	-.0868	1.0											
	2154600 =	-.3591	-.3591	-.3591		1.0										
	1065600 =	-.1776	-.1776	-.1776			1.0									
	154200. =	-.0257	-.0257	-.0257				1.0								
	351000. =	-.0585	-.0585	-.0585					1.0							
	1753800 =	-.2923	-.2923	-.2923						1.0						
MAXIMUM CAPACITY CONSTRAINTS	636000. ≥				1.0											
	3600000 ≥					1.0										
	1980000 ≥						1.0									
	4350000 ≥				1.0	1.0	1.0									
	180000. ≥							1.0								
	600000. ≥								1.0							
	750000. ≥							1.0	1.0							
	2685000 ≥									1.0						
MINIMUM ALLOWANCE CONSTRAINTS	360000. ≤				1.0											
	312000. ≤					1.0										
	225000. ≤						1.0									
	42000. ≤							1.0								
	171000. ≤								1.0							
	222000. ≤									1.0						
COMPANY PRORATIONS	0.0 =				-.35						1.0					
	0.0 =					-.28						1.0				
	0.0 =						-.18						1.0			
	0.0 =							-.33						1.0		
	0.0 =								-.41						1.0	
	0.0 =									-.22						1.0

APPENDIX B

REFINERY MODEL

(See Folder)

APPENDIX C

PRODUCT SPECIFICATIONS

Gasoline

Reid Vapour Pressure.....11PSI Minimum

End Point.....410°F Maximum

50% Boiling Point.....190-230°F

Octane Number	Premium Gasoline	Regular Gasoline
Research	97	92
Motor	89	85

Diesel

Cetane Index	45	Minimum
Pour Point	20°F	Maximum

APPENDIX D

PRODUCT DISTRIBUTION MODEL

(See Folder)

APPENDIX E - DEMAND VECTORS

Distribution Centre	Vector A			Vector B		
	Premium Demand Factor xTGD[a]	Regular Demand Factor xTGD[a]	Diesel Demand Factor xTGD[a]	Premium Demand Factor xTGD[a]	Regular Demand Factor xTGD[a]	Diesel Demand Factor xTGD[a]
1	.0864	.2016	.1440	.0864	.2016	.2016
2	.0636	.1484	.1060	.0636	.1484	.1484
3	.0201	.0469	.0335	.0201	.0469	.0469
4	.0171	.0399	.0285	.0171	.0399	.0399
5	.0189	.0441	.0315	.0189	.0441	.0441
6	.0120	.0280	.0200	.0120	.0280	.0280
7	.0102	.0238	.0170	.0102	.0238	.0238
8	.0120	.0280	.0200	.0120	.0280	.0280
9	.0045	.0105	.0075	.0045	.0105	.0105
10	.0081	.0189	.0135	.0081	.0189	.0189
11	.0093	.0217	.0155	.0093	.0217	.0217
12	.0108	.0252	.0180	.0108	.0252	.0252
13	.0189	.0441	.0315	.0189	.0441	.0441
14	.0042	.0098	.0070	.0042	.0098	.0098
15	.0039	.0091	.0065	.0039	.0091	.0091
Total	.3000	.7000	.5000	.3000	.7000	.7000

[a] TGD = Total Gasoline Demand.

APPENDIX D - PRODUCT DISTRIBUTION MODEL

Objective Row	N	Premium Gasoline Volume Distributed From Refinery A	Premium Gasoline Volume Distributed From Refinery B	Premium Gasoline Volume Distributed From Product Pipeline Terminal	Regular Gasoline Volume Distributed From Refinery A	Regular Gasoline Volume Distributed
Premium Refinery A	L	3.05 3.05 3.57 3.01 3.81 3.05 3.41 3.77 3.89 3.81 3.[illegible] 3.77 3.49 3.41	3.05 3.05 3.57 3.01 3.41 3.05 3.41 3.77 3.89 3.61 3.49 3.49 3.77 3.45 3.41	2.91 2.91 3.43 3.47 3.67 3.51 3.27 3.63 3.75 3.47 3.15 3.15 3.63 3.41 3.27	3.05 3.05 3.57 3.01 3.41 3.05 3.41 3.77 3.89 3.61 3.49 3.49 3.77 3.45 3.41	3.05 3.05 3.57 3.01 3.41 3.05 3.41 3.77 3.[illegible]
Premium Refinery B	L	1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0	1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0	1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0	1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0	1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
Regular Refinery A	L					
Regular Refinery B	L					
Diesel Refinery A	L					
Diesel Refinery B	L					
Product Pipeline	L					
1	F	1.0	1.0	1.0	1.0	1.0
2	E	1.0	1.0	1.0	1.0	1.0
3	E	1.0	1.0	1.0	1.0	1.0
4	E	1.0	1.0	1.0	1.0	1.0
Premium Gasoline Demand	E	1.0	1.0	1.0	1.0	1.0
6	E	1.0	1.0	1.0	1.0	1.0
7	E	1.0	1.0	1.0	1.0	1.0
8	E	1.0	1.0	1.0	1.0	1.0
9	E	1.0	1.0	1.0	1.0	1.0
at Distribution Point 10	E	1.0	1.0	1.0	1.0	1.0
11	E	1.0	1.0	1.0	1.0	1.0
12	F	1.0	1.0	1.0	1.0	1.0
13	E	1.0	1.0	1.0	1.0	1.0
14	E	1.0	1.0	1.0	1.0	1.0
15	E	1.0	1.0	1.0	1.0	1.0
1	R				1.0	1.0
2	E				1.0	1.0
3	E				1.0	1.0
4	E				1.0	1.0
Regular Gasoline Demand	E				1.0	1.0
6	E				1.0	1.0
7	E				1.0	1.0
8	E				1.0	1.0
9	E				1.0	1.0
at Distribution Point 10	E				1.0	1.0
11	E				1.0	1.0
12	F				1.0	1.0
13	E				1.0	1.0
14	E				1.0	1.0
15	E				1.0	1.0
1	R					
2	E					
3	E					
4	E					
Diesel Demand	E					
6	E					
7	E					
8	E					
9	E					
at Distribution Point 10	E					
11	E					
12	F					
13	F					
14	E					
15	E					
1	0.0	-1.0			-1.0	
2	0.0	-1.0 -1.0			-1.0 -1.0	
3	0.0	-1.0 -1.0			-1.0 -1.0	
4	0.0	-1.0 -1.0			-1.0 -1.0	
Conversion to	0.0	-1.0 -1.0			-1.0 -1.0	
Truck Tanker Trips	0.0	-1.0 -1.0			-1.0 -1.0	
from Refinery A to	0.0	-1.0 -1.0			-1.0 -1.0	
Distribution Point	0.0	-1.0 -1.0			-1.0 -1.0	
9	0.0	-1.0 -1.0			-1.0 -1.0	
10	0.0	-1.0 -1.0			-1.0 -1.0	
11	0.0	-1.0 -1.0			-1.0 -1.0	
12	0.0	-1.0 -1.0			-1.0 -1.0	
13	0.0	-1.0 -1.0			-1.0 -1.0	
14	0.0	-1.0 -1.0			-1.0 -1.0	
15	0.0	-1.0 -1.0			-1.0 -1.0	
1	0.0		-1.0 -1.0			-1.0 -1.0
2	0.0		-1.0 -1.0			-1.0 -1.0
3	0.0		-1.0 -1.0			-1.0 -1.0
4	0.0		-1.0 -1.0			-1.0 -1.0
Conversion to	0.0		-1.0 -1.0			-1.0 -1.0
Truck Tanker Trips	0.0		-1.0 -1.0			-1.0 -1.0
from Refinery B to	0.0		-1.0 -1.0			-1.0 -1.0
Distribution Point	0.0		-1.0 -1.0			-1.0 -1.0
9	0.0		-1.0 -1.0			-1.0 -1.0
10	0.0		-1.0 -1.0			-1.0 -1.0
11	0.0		-1.0 -1.0			-1.0 -1.0
12	0.0		-1.0 -1.0			-1.0 -1.0
13	0.0		-1.0 -1.0			-1.0 -1.0
14	0.0		-1.0 -1.0			-1.0 -1.0
15	0.0		-1.0 -1.0			-1.0 -1.0
1	0.0			-1.0		
2	0.0			-1.0 -1.0		
3	0.0			-1.0 -1.0		
4	0.0			-1.0 -1.0		
Conversion to	0.0			-1.0 -1.0		
Truck Tanker Trips	0.0			-1.0 -1.0		
from Product Pipeline Terminal	0.0			-1.0 -1.0		
8	0.0			-1.0 -1.0		
to Distribution Point 9	0.0			-1.0 -1.0		
10	0.0			-1.0 -1.0		
11	0.0			-1.0 -1.0		
12	0.0			-1.0 -1.0		
13	0.0			-1.0 -1.0		
14	0.0			-1.0 -1.0		
15	0.0			-1.0 -1.0		
Trucks Available Refinery A	0.0					
Trucks Available Refinery B	0.0					
Trucks Available Pipeline Terminal	0.0					

APPENDIX B - REFINERY MODEL

Objective Row	N	Crude 1 Distillation	Crude 2 Distillation	Crude 3 Distillation	Fluid Catalytic Cracking	Hydrodesulphorisation	Reforming	Thermal Cracking	Polymerisation
Crude Distillation Capacity	+0/000.	-.[illegible]	-.[illegible]	-.[illegible]	-.[illegible]	-.[illegible]	-.[illegible]	-.[illegible]	
Refinery A Fluid Catalytic Cracking Capacity	19/000.	1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0	1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0	1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0	1.0 1.0	1.0 1.0 1.0 1.0 1.0	1.0 1.0	1.0 1.0 1.0 1.0	
Capacities Hydrodesulphorisation Capacity	27000.								
Reforming Capacity	18/000.								
Thermal Cracking Capacity	21/000.								
Polymerisation Capacity	14000.								
Crude Distillation Capacity	10/000.								
Refinery B Fluid Catalytic Cracking Capacity	9/000.								
Capacities Hydrodesulphorisation Capacity	15000.								
Reforming Capacity	8000.								
Thermal Cracking Capacity	10/000.								
Polymerisation Capacity	9000.								
Crude 1 Availability	+00000.	1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0							
Crude 2 Availability	40/000.		1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0						
Crude 3 Availability	50/000.			1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0					
Crude 4 Availability	+00000.								
Fuel Gas	0.0	-.[illegible]	-.[illegible]	-.[illegible]	.[illegible]	-.[illegible]	.[illegible]	.[illegible]	
Propane	0.0	.[illegible]	.[illegible]	.[illegible]	.[illegible]	-.[illegible]	.[illegible]	.[illegible]	
Isobutane	0.0	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	
Butane	0.2	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	
Naptha Gasoline	0.0	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	
	7.0	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	
	0.0	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	.[illegible]	

Regular Gasoline Volume Distributed From Refinery B

Regular Gasoline Volume Distributed From Product Pipeline Terminal

Diesel Volume Distributed From Refinery A

Diesel Volume Distributed From Refinery B

Diesel Volume Distributed ... Terminal

Thermal Coking

Polymerization

Premium Gasoline Blending

Premium Gasoline

Regular Gasoline Blending

Regular Gasoline

Company Truck Tanker Trips From Refinery A

Company Truck Tanker Trips From Refinery B

Company Truck Tanker Trips From Product Pipeline Terminal

Truck Tankers

Diesel Blending

Diesel

Propane

Isobutane Butane

Jet Fuel

Crude & Distillation

Crude & Distillation

Fluid Catalytic Cracking

Hydrodesulfurization

Comercial Truck Tanker Trips From Refinery A	Comercial Truck Tanker Trips From Refinery B	Commercial Truck Tanker Trips From Product Pipeline Terminal
-7.1 152.1 -84.12 -7.1 -7.1 -7.1 1.3e44 171.12 125.44 62.76 58.88 -58.88 -80.00 -53.76 -44.64	-152.12 -17.12 -74.88 -69.76 -87.12 -7.1 48.64 -40.00 -110.08 -104.96 -130.56 -120.32 -152.32 -171.52 -192.30	-85.12 -74.88 -17.12 -130.56 -152.32 -145.92 -44.64 -80.00 -47.24 -17.12 -64.76 -44.64 -85.12 -110.08 -110.56
183.0 183.0 181. 181. 181. 181. 181. 181. 181.0 181.0 181.0 181.0 181.0 183.0	181. 183.0 181.0 181. 181. 181. 181.0 181.0 183.0 183.0 181.0 183.0 183.0 183.0 183.0 183.0	184.0 183.0 183.0 183.0 181.0 181.0 181.0 181.0 181.0 181.0 181.0 183.0 183. 181.0 181.0

| | Hydrodesulphurization | | | | | Reforming | | Thermal Coking | | | | Polymerization | | | Premium Gasoline Blending | | | | |

APPENDIX B - REFINERY MODEL

			Crude 1 Distillation										Crude 2 Distillation										Crude 3 Distillation										Fluid Catalytic Cracking		Hydrodesulphurisation					Reforming		Thermal Coking				Polymerization			
Objective Row																																																	
Refinery A Capacities	Crude Distillation Capacity	402000.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0														
	Fluid Catalytic Cracking Capacity	142000.																															1.0	1.0														
	Hydrodesulphurisation Capacity	276000.																																	1.0	1.0	1.0	1.0	1.0								
	Reforming Capacity	140000.																																						1.0	1.0						
	Thermal Cokina Capacity	210000.																																								1.0	1.0	1.0	1.0		
	Polymerization Capacity	19000.																																											1.0	1.0
Refinery B Capacities	Crude Distillation Capacity	402000.																																												
	Fluid Catalytic Cracking Capacity	142000.																																												
	Hydrodesulphurisation Capacity	134000.																																												
	Reforming Capacity	70000.																																											
	Thermal Cokina Capacity	100000.																																												
	Polymerization Capacity	9000.																																												
	Crude 1 Availability	400000.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0																																				
	Crude 2 Availability	400000.										1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0																										
	Crude 3 Availability	402000.																					1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0														
	Crude 4 Availability	400000.																																												
Conversion Process Refinery A	Fuel Gas	0.0	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	-.018	.070	.096	-.022	-.022	-.022	-.022	-.022	.076	.112	.068	.068	.068	.068	.100	.100		
	Propane	0.0	.034	.034	.034	.034	.034	.034	.034	.034	.034	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.011	.018								.026	.026	.026	.026				
	Isobutane	0.0	.004	.004	.004	.004	.004	.004	.004	.004	.004	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006	.031	.047								.008	.008	.008	.008			-1.0	-1.0
	Butane	0.0	.017	.017	.017	.017	.017	.017	.017	.017	.017	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.019	.019	.019	.019	.019	.019	.019	.019	.019	.019	.002	.003								.025	.025	.025	.025				
	Naptha Gasoline	0.0	.224	.224	.224	.224	.224	.224	.224	.224	.224	.213	.213	.213	.213	.213	.213	.213	.213	.213	.213	.260	.260	.260	.260	.260	.260	.260	.260	.260	.260	.340	.340	-1.0	-1.0	-1.0	-1.0	-1.0									
		0.0	.184	.184	.184	.184	.184	.184	.184	.184	.184																																				
		0.0				.105	.105	.105																																							
		0.0							.095		.095	.095																																			
	Light Straight Run	0.0										.195	.195	.195																																
		0.0													.147	.147	.147																												
		0.0																.119	.117	.117																										
		0.0																			.140	.140	.140																							
		0.0	.095			.095			.095															.130	.130	.130																				
		0.0		.115	.115		.115			.115																	.100	.100	.100																	
	Heavy Straight Run	0.0										.112	.111		.112	.111		.112	.111																										
		0.0												.152			.152			.152																										
		0.0																			.133	.130	.130			.120	.120	.120																		
		0.0																						.133	.130	.130			.120	.120	.120																
	Atmospheric Gas Oil	0.0	.216	.177	.177	.216	.177	.177	.216	.196	.177	.207	.188	.167	.207	.188	.167	.207	.187	.167	.195	.195	.195	.195	.195	.195	.195	.195	.195	.195	.195	-1.0	-1.0								-1.0	-1.0						
	Reduced Crude	0.0	.244	.244	.244	.244	.244	.244	.244	.244	.244	.211	.211	.211	.211	.211	.211	.211	.211	.211	.215	.215	.215	.215	.215	.215	.215	.215	.215	.215	.215	.034	.030								.013	.013	.013	.013				
	Propane	0.0																														.012	.044								.016	.016	.016	.016				
	Butane	0.0																														.007	.023									-1.0		-1.0				
	Fluid Catalytic Cracked Gasoline	0.0																														.107	.250	.170	.100	.100	.200	.250	-1.0	-1.0							
	Cycle Oil	0.0																																.625	.600	.295	.795	.145									
	Polymerised Straight Run Gasoline	0.0																																		.330		.430	.445								
	Reformer Feed	0.0																																						.834							
	Jet Fuel	0.0																																							.400	.400	.442	.442				
	Reformate 84 Research Octane	0.0																																							.100	.100					
	Reformate 95 Research Octane	0.0																																							.257	.257	.257	.257				
	Thermal Coke Gasoline	0.0																																							.047	.047	.047	.057				
	Thermal Coke Distillate	0.0																																										.720	.720		
	Lumber Fuel	0.0																																												
	Coke	0.0																																												
	Polymerised Gasoline	0.0																																												
Premium Gasoline Blending Refinery A	Reid Vapour Pressure	0.0																																												
	180°F 82% Boiling Point	0.0																																												
	230°F 50% Boiling Point	0.0																																												
	Research Octane Number	0.0																																												
	Motor Octane Number	0.0																																												
	Gasoline Blended	0.0																																												
Regular Gasoline Blending Refinery A	Reid Vapour Pressure	0.0																																												
	180°F 82% Point	0.0																																												
	230°F 50% Boiling Point	0.0																																												
	Research Octane Number	0.0																																												
	Motor Octane Number	0.0																																												
	Gasoline Blended	0.0																																												
Diesel Blending Refinery A	Cetane Index *	0.0																																												
	Pour Point	0.0																																												
	Diesel Blended	0.0																																												
Conversion Process Refinery B	Fuel Gas	0.0																																												
	Propane	0.0																																												
	Isobutane	0.0																																												
	Butane	0.0																																												
	Naptha Gasoline	0.0																																												
		0.0																																												
		0.0																																												
	Light Straight Run	0.0																																												
		0.0																																												
		0.0																																												
		0.0																																												
	Heavy Straight Run	0.0																																												
		0.0																																												
		0.0																																												
	Atmospheric Gas Oil	0.0																																												
	Reduced Crude	0.0																																												
	Propane	0.0																																												
	Butane	0.0																																												
	Fluid Catalytic Cracked Gasoline	0.0																																												
	Cycle Oil	0.0																																												
	Polymerised Straight Run Gasoline	0.0																																												
	Reformer Feed	0.0																																												
	Jet Fuel	0.0																																												
	Reformate 84 Research Octane	0.0																																												
	Reformate 95 Research Octane	0.0																																												
	Thermal Coke Gasoline	0.0																																												
	Thermal Coke Distillate	0.0																																												
	Lumber Fuel	0.0																																												
	Coke	0.0																																												
	Polymerised Gasoline	0.0																																												
Premium Gasoline Blending Refinery B	Reid Vapour Pressure	0.0																																												
	180°F 82% Point	0.0																																												
	230°F 50% Boiling Point	0.0																																												
	Research Octane Number	0.0																																												
	Motor Octane Number	0.0																																												
	Gasoline Blended	0.0																																												
Regular Gasoline Blending Refinery B	Reid Vapour Pressure	0.0																																												
	180°F 82% Point	0.0																																												
	230°F 50% Boiling Point	0.0																																												
	Research Octane Number	0.0																																												
	Motor Octane Number	0.0																																												
	Gasoline Blended	0.0																																												
	Cetane Index *	0.0																																												
	Pour Point	0.0																																												
	Diesel Blended	0.0																																												

	Polymerization		Premium Gasoline Blending																						Premium Gasoline	Regular Gasoline Blending																						Regular Gasoline	

Diesel Blending	Diesel	Propane	Isobutane	Butane	Jet Fuel	Naphtha Feed	Coke	Crude 3 Distillation	Crude 4 Distillation	Fluid Catalytic Cracking	Hydrodesulphurization	Reforming	Thermal Coking	Polymerization
		-1.0	-1.0	-1.0										
	-45.0 -1.0													
	1.0													

Premium Gasoline Blending	Premium Gasoline	Regular Gasoline Blending	Regular Gasoline	Diesel Blending	Diesel	Propane	Isobutane	Butane	Jet Fuel	Bunker C Fuel	Coke